O.R.E. Trackpoint Acoustic Range/Bearing Receiver Evaluation

D.L. McKeown

Atlantic Oceanographic Laboratory
Ocean Science and Surveys, Atlantic
Department of Fisheries and Oceans

Bedford Institute of Oceanography
P.O. Box 1006
Dartmouth, Nova Scotia B2Y 4A2

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D.L. McKeown

Atlantic Oceanographic Laboratory

Ocean Science and Surveys, Atlantic

Department of Fisheries and Oceans

Bedford Institute of Oceanography

P.O. Box 1006

Dartmouth, Nova Scotia

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ABSTRACT

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The Atlantic Oceanographic Laboratory has a requirement for an ultrashort baseline acoustic receiver operating at around 10 kHz to measure the relative bearing between acoustic sources on moorings and the recovery ship. In an effort to satisfy this need, the purchase of a TRACKPOINT O.R.E. model 450 B Acoustic Range/Bearing Receiver was contemplated. Because of a concern about the effects on the receiver of ambient and ship generated acoustic noise in the operational environment, a unit underwent extensive testing prior to purchase. This document describes the nature of these tests at sea, at an acoustic test facility and in a shallow embayment. The results of each test are summarized and discussed. It is concluded that the receiver will not satisfy the Laboratory's needs because it is unable to adequately determine bearing in the presence of acoustic noise produced by the ship it would most often be employed with, namely C.S.S. Hudson.

RÉSUMÉ

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Le Laboratoire océanographique de l'Atlantique a besoin d'un récepteur acoustique à base très courte fonctionnant autour de 10 kHz, pour mesurer la différence de relèvement entre des sources sonores installées sur des corps-morts et le navire de récupération. Dans le but de répondre à ce besoin, l'achat d'un récepteur acoustique du type Acoustic Range/Bearing Receiver, modèle 450B, de la Trackpoint O.R.E., a été envisagé. À cause de certaines préoccupations relatives aux effets sur le récepteur du bruit acoustique ambiant et du bruit produit par le navire dans des conditions opérationnelles, un de ces récepteurs a été soumis à des essais complets avant l'achat. Le présent document décrit la nature des essais réalisés en mer, dans une installation d'essais acoustiques et dans un golfe peu profond. Les résultats de chaque essai sont résumés et commentés. L'auteur conclut que le récepteur n répondra pas aux besoins du Laboratoire parce qu'il est incapable de déterminer adéquatement le relèvement d'une source en présence du bruit acoustique produit par le navire sur lequel il serait le plus fréquemment utilisé, soit le NSC Hudson.

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I. INTRODUCTION

On the sea surface, oceanographic instruments can be positioned by using optical or electromagnetic methods. Unfortunately, these signals penetrate only a few tens of metres below the surface so tht, throughout most of the ocean's volume, such positioning methods are unsuitable. Therefore, it has become the practice to rely on acoustic signals for positioning sub-surface instruments. While frequencies in the order of tens of Hertz propagate thousands of miles through the ocean, they require large arrays for signal detection so are limited to applications such as tracking SOFAR floats from shore based stations. Frequencies in the range of 5 to 10 kilohertz are commonly used to position instruments over shorter distances of up to 50 kilometres during more localized oceanographic experiments. Systems operating in this range are of two types, being either shipr eferenced or bottom referenced. The latter are best suited to situations where a high level of positional accuracy is required over an area of a few square kilometers. The former are more suitable in cases where the investigator is willing to accept a lower level of positioning accuracy in return for faster set-up times and greater flexibility in operating area.

There are several positioning problems at the Bedford Institute of Oceanography (BIO) which could be solved through the acquisition of a suitable ship-referenced acoustic positioning system and development of appropriate operating methodology. These include:

(1) Methods for relocating moorings on the sea floor in regions of inadequate surface navigation aids;

(2) Methods of searching for moorings which come to the surface upon activation of the release but are lost because of poor

visibility;

(3) Methods for tracking vertical current meters and other neutrally buoyant drifters;

(4) Methods of navigating mooring recovery devices into contact with moorings which fail to release;

(5) Methods of positioning towed, cable controlled and autonomous vehicles such as Huntec Seabed II, DART and ARCS;

(6) Methods of positioning sea floor samplers with respect to geological features such as iceberg scours;

(7) Methods of positioning the ship relative to a sampling device such as the BIO Electric Rock Core Drill in order to improve station keeping ability.

Ship referenced acoustic positioning systems date back to World War I (Lasky, 1977) with substantial literature having been published on the subject. Some of this (e.g. Baxter, 1964) concerns short baseline systems (SBS) wherein the separation between the hydrophones is some small multiple of the wavelength. Other papers discuss ultra- or super- short baseline systems (USBS) (e.g. Richardson (1978), Vestgaard and Hansen (1978)) where hydrophone separation is a fraction of a wavelength. There is also a substantial body of literature on the relative merits of SBS, USBS and LBS (long baseline systems) (e.g. Van Calcar, 1970), the latter falling into the class of bottom referenced positioning systems.

The author has been involved in the search for a suitable ship referenced acoustic positioning system for use on the Institute's ships since the early 70's. During the course of that work, an AMF model 301 USBS receiver was evaluated and rejected as being unsuited to our needs, a short-baseline system was developed in-house and has been operational on

CSS Hudson for some years, and a second generation ultra-short baseline system, the ORE Trackpoint, has undergone evaluation. The SBS unit has reached the end of its working life and is being removed from service this year. This document is a report on the trials carried out on the ORE Trackpoint Model 450 receiver in the context of this Institute's specific requirements. It is not intended to be a definitive evaluation of that piece of equipment.

II. SYSTEM SPECIFICATION

BIO's standard current meter mooring employs EG&G model 325, 723, etc. acoustic transponders as the prime recovery aid. These are set up to respond at 10.0 kHz when interrogated at 11.0 kHz. While it is possible to put aditional acoustic sources on the mooring, it was deemed very important that a range/bearing receiver be found which operated at 10.0 kHz. It would thus be compatible with the existing releases and, operating at that frequency, there was every likelihood that it would detect acoustic sources at slant ranges of several thousand metres. For mooring relocation and station keeping functions, a relative bearing accuracy of ±5° was deemed adequate although, for some of the other items listed in section 1, a bearing accuracy of ±1° is called for. The third specification of importance was installation and operating convenience. In other words, it was desired to have a system which entailed the minimum of transducer installation effort so that the unit could be moved readily from ship to ship. Also, the equipment had to be simple to operate since it would be used by many different people in varying circumstances throughout each field season.

Previous SBS and USBS experience had identified ship generated

acoustic noise as a great hinderence to successful operation of hull mounted transducers. It is difficult to specify a particular signal-to-noise detection threshold in such a circumstance so a more pragmatic approach was tried. It was decided that an USBS receiver which met the other requirements listed above and fell into an acceptable price range (less than $60,000) would be evaluated at sea to determine its operational characteristics in the presence of ship generated noise.

III. THE ORE MODEL 450 ACOUSTIC RANGE/BEARING RECEIVER

In early 1980, a search of commercial literature indicated that only the ORE model 450 Acoustic Range/Bearing Receiver (TRACKPOINT) appeared to meet the above criteria. The equipment is in three parts, a Receiving Hydrophone, a Vertical Reference Unit, and a Surface Display Unit.

The Receiving Hydrophone consists of three hydrophones set at 120° to each other and spaced less than about 3/8 λ apart at the highest frequency of operation. The proper transducer must be selected for the chosen range of operating frequency. Contained within the transducer housing are hydrophone preamplifiers capable of driving up to 150 m of cable. The overall size of the transducer and protective cage is approximatey 0.23 m dia. x 0.25 m high. Welded to the top of the cage is av ertical piece of angle iron, its apex pointing toward relative bearing 000°. Signals from this unit are transmitted to the Surface Display Unit via a multiconductor cable.

To correct for receiving hydrophone array tilt, a Vertical Reference Unit is supplied. This contains two orthogonal pendulum potentiometers which send their signals to the Surface Display Unit. It should be

mounted near the centre of rotation of the vessel to minimize acceleration induced tilt erros. It need not be installed perfectly horizontal as the Surface Display Unit is designed to compensate for minor tilt offsets.

The receiver is basically an analogue device and functions in the following manner. Figure 1a illustrates a case where an acoustic source is on or near the right bisector of hydrophone baseline B-C. As the signal reaches each of the hydrophones, it produces the acoustic pressure waveforms at hydrophones A, B and C shown in Figure 1b. These are converted to equivalent time varying electrical signals by the hydrophones. About 10 cycles after the first cycle of signal reaches each hydrophone, a phase locked loop in each of the three receivers of the Surface Display Unit begins the recognition process and requires about 0.5 msec to lock onto the signal. During the next 20 cycles (40 zero crossings), the phase delays between pairs of hydrophone signals are measured 40 times and averaged. Appropriate analogue circuitry corrects for transducer tilt and computes and displays relative bearing. A fast attack, slow decay AGC is then activated to set up amplifier gains in preparation for the next tone burst arrival. Every sixth time a signal is detected, the unit carries out an internal calibration sequence to correct for fixed electrical phase errors between channels. A more thorough description of each element of the Surface Display Unit follows.

Each hydrophone drives a high-gain symmetrical-clipper (hard limiting) amplifier. These amplifiers include high-pass filters which are 3 db down at 10.0 kHz and are incorporated to reduce the effects of ambient noise. They also have two automatic gain controls (AGC). First, there is a fast attack, slow decay (tens of seconds) AGC to set up amplifier gains in preparation for the next tone burst arrival. Secondly, there is a very

slow (minutes) AGC which adjusts gains in response to long term changes in ambient noise. There is also a manual attenuator which can be employed when necessary to reduce interference from multiple reflections when the source signal is very strong.

Upon leaving the amplifiers, the three hydrophone signals enter wideband phase-lock loop or tone decoders where two types of output are generated. Firstly, the decoders generate "Enable" logic levels for the remainder of the detection circuitry as well as light LED's to indicate that an acceptable signal has been identified. These LED's are an important indicator of system performance. Secondly, the output signals activate three narrow band phase-lock loops to produce clean square waves suitable for phase measurement.

When all three receivers generate "Enable" signals, a complex and clever timing/counting system measures the phase differences between hydrophone signal pairs a total of 40 times and averages the results. These phase differences are converted to equivalent DC voltages and certain scalar and vector arithmetic is done using analogue circuitry to deduce equivalent range and bearing information. The resulting voltages are corrected for array tilt using inputs from the vertical reference unit and scaled for display. The result of this processing is a pair of voltages representing the forward (y) and athwartships (x) components of the source location with respect to the ship.

A final electronic module is provided which drives the x and y plates of a CRT between Ø volts and x and y volts respectively to produce a cursor whose direction represents relative bearing of the source with respect to the ship and whose length represents horizontal range as a fraction of source depth with unity corresponding to full scale deflection

(FSD). A Z-axis or intensity signal is generated at the same time which brightens the cursor when the voltages are updated and then permits it to fade away during the next 5 to 10 seconds.

Every sixth time a signal is detected, the Surface Display Unit disconnects the hydrophone signals from the amplifier inputs. In their place, it proceeds to measure the electrical phase differences between the channels. This information is stored in the timing/counter system where it is used to correct phase difference measurements during the subsequent five fixes.

The Surface Display Unit also contains a separate audio receiver. Incoming signals are mixed with an internal beat frequency oscillator (BFO) to produce an equivalent audio output at about 3 kHz. This information is used in conjunction with the "Enable" LED's when there is a need to confirm correct system operation or to diagnose problems.

A complete specification for the Trackpoint system is included as an Appendix to this report. Further details concerning circuit operations are contained in the receiver manual supplied by the manufacturer (ORE, 1980).

IV. FIELD TRIALS

1. General

Five separate field trials of the receiver were carried out. During the first three, the receiving system was obtained directly from the manufacturer, ORE of Falmouth, Mass., and the trials took place aboard CSS Hudson in deep water. The fourth and fifth trials employed a receiver kindly loaned by the Canadian Armed Forces Fleet Diving Unit (Atlantic). The fourth trial took place aboard CSS Hudson on the Scotian Shelf and the

final one in Bedford Basin adjacent to the Institute.

ii. Trial #1 - June 1980

In June 1980, a system was leased and installed on CSS Hudson for trials during drilliilng operations on the Mid-Atlantic Ridge at 36°N. This system had a gimbled hydrophone array which was mounted on the end of a 9 m pole over the starboard side of the ship. It was set by the manufacturer to receive signal at 11.0 kHz from an AMF Model 360 beacon pinger installed on the drill. Sometimes it gave consistent readings but not often enough to inspire confidence. At the end of the cruise, it was returned to ORE who discovered that one of the hydrophone leads was broken. It was thought that this might have caused the problem.

iii. Trial #2 - April 1981

ORE very kindly loaned the unit a second time free-of-charge for a further evaluation during the Halifax-Puerto Rico leg of the 1981 CSS Hudson BIOSTAT cruise. This time the unit was set up to operate at 27 kHz and ORE supplied a suitable sound source. Bad weather prevented any extensive trials being done and no significant conclusions were reached.

iv. Trial #3 - July 1982

During the winter of 81-82 it was decided that the Institute still needed such a system and the ORE Trackpoint still appeared to be the most appropriate choice. Therefore, it was decided that a unit would again be leased and tested during the 1982 Mid-Atlantic Ridge cruise. Three objectives were identified:

(a) establish quantitatively the system specifications during

actual field operations;

(b) verify that it would provide the bridge with drill position relative to the ship during drill stations to enhance station keeping capability;

(c) evaluate its performance as a positioning system for towed bodies.

The company was informed that the work be done at frequencies of 10 to 12 kHz and thus it was expected that a model 441 A hydrophone array would be shipped. The packing list indicated a model 441 C better suited to 20-30 kHz, had been shipped. No model number could be found on the actual unit. The manual said a 441 C would work "with some degradation in performance" and, since the ship was by then some distance from port, it was used as delivered.

All of the equipment appeared to be manufactured to a high standard. No problems were encountered in installing it. The Vertical Reference Unit was installed in the ship's gravimeter room and connected to the Surface Display Unit via existing ship's wiring. It was our intention to conduct some preliminary trials with the transducer suspended onropes amidships on the starboard side, move it about to find the best operating location, then, when an acceptable level of performance was established, mount it on a hydraulic ram so that it would be extended through a gate valve in the bottom of the ship.

Except in rare instances, no echo sounders were being operated on the ship during these Trackpoint tests. Acoustically the ship, CSS Hudson, is considered to be relatively noisy. Aside from the usual machine generated noise, substantial acoustic disturbances are caused by aerated water being swept past the transducers when the ship goes astern or

operates its bow thruster while holding station.

During these trials, a long baseline acoustic positioning system was being used to position both ship and a sea floor sampling device, a rock core drill. This involved alternate 11.0 kHz acoustic transmissions at 10 second intervals from ship and drill with source levels of about 190 db re 1 μPa @ 1 m and pulse lengths in the order of 20 msec. In response to these transmissions, a number of sea floor transponders would reply in the frequency band 8.0 to 10.5 kHz. Attached to the drill cable about 30 m above the actual sampler was a free running 12 kHz pinger emitting a 1 msec long tone burst every second at a level of about 183 db re 1 μPa @ 1 m. It was not intended that the Trackpoint should respond to this latter source but, as it was emitting a strong signal at a frequency only 10% removed from the receiver frequency, interference was a possibility. While not an ideal acoustic environment, this is typical of the conditions under which the Trackpoint system would be expected to work.

The Trackpoint invariably indicated the correct bearing of the ship's echo sounding transducer approximately 17 m away when the latter emitted a signal at 11.0 kHz. Similarly, bearings were correct when an 11.0 kHz pinger was streamed aft of the ship about 188 m. As the range increased further, the number of successful replys decreased until, at a range of about 1000 m, very few measurements of bearing were obtained. During a subsequent lowering of the drill, the receiver detected signals from the same pinger to 2700 m slant range. At this range, the standard deviation of relative bearing about a mean over 44 fixes was 8.6°. Unfortunately during this and subsequent experiments, the relative bearing was usually in error by 180°. It was noted that some slight improvement could be achieved if the shipboard transducer was moved away from the ship's

side. ORE attributed the 180° bearing error to a small amount of water they found in the hydrophone preamplifier pressure case subsequent to the sea trials (A. Griswold, personal communication, Oct. 15, 1982).

v. Trial #4 - July 1983

Through the generosity of the Canadian Armed Forces Fleet Diving Unit (Atlantic), an identical ORE model 450 Trackpoint receiver was obtained for further trials aboard CSS Hudson in July 1983 on the Scotian Shelf. The objective of this experiment was to determine how well a Trackpoint receiver in good working order would function aboard CSS Hudson. Once again the transducer was a model 441 C (20-30 kHz) although the frequency of operation was 11.5 kHz. It was mounted on the end of a vertical faired pole, pivoted at the top and stayed fore and aft so that it only had freedom to move on the roll axis. Depth of the transducer was approximately 5 m and it was positioned at about the same position along the starboard side of the ship as it had been in all previous trials. The acoustic source in this case was Datasonics model UAT-371 with a source level of +195 db re 1 μ Pa @ 1 m suspended about 2 m beneath a surface float. The results of these experiments are discussed in section V.

vi. Trial #5 - July/Aug., 1983

Subsequent to the fourth and final sea trial, a series of experiments were carried out in Bedford Basin, an enclosed body of water adjacent to the Institute. These trials had two objectives:

(1) to determine how well the receiver worked in the absence of significant ambient noise;

(2) to determine whether poor performance at sea was caused

by ship produced noise or reflections from the hull.

The results of these experiments are discussed in section V.

V. RESULTS AND DISCUSSION

i. Sea Trials - Acoustic vs Visual Bearing

During the sea trials of July 1983, the ship steamed slowly around an acoustic source located at a depth of about 50 m at ranges varying from 500 to 900 m while visual and acoustic relative bearings were measured. The visual bearings were obtained by sighting through a pelorous at the buoy supporting the transponder. Accuracy of this measurement is estimated to be ±2°. Figure 2 illustrates the visual and acoustic bearings as a function of time and Figure 3 illustrates the degree of correlation between the two. It should be noted that, although this represents all of the data collected during the time interval selected, data obtained prior and subsequent to this period was often of much lower quality.

A straight line was fitted to the rather scattered data of Figure 3. It was found to have a slope of 1.065 indicating that, overall, the acoustic bearings were representative of the visual relative bearing of the source. The standard deviation of the difference between the acoustic and visual relative bearings was also computed and was determined to be 20.6°. This confirms the impression given by Figure 3 that, generally speaking, the trend of the acoustic bearings represents the actual bearing of the source but any individual acoustic fix is likely to be substantially in error. The question which then must be addressed is whether this variability in the measured acoustic bearing is caused by:

(1) a malfunction of the Trackpoint receiver;

(2) interference caused by signals reaching the transducer

after reflection from the ship's hull;

(3) acoustic noise generated by the ship;

(4) source/transducer angle less than 10°;

(5) other causes

ii. Trackpoint Performance Under 'Ideal' Conditions

In an attempt to determine how well the Trackpoint receiver operates under 'ideal' acoustic conditions, the unit was installed on the Defence Research Establishment (Atlantic) Acoustic Test Barge in Bedford Basin. The same acoustic source as used in the July 1983 sea trial, a Datasonics UAT-371 transponder, was used. It was suspended at a depth of 5 m first at a range of 36 m then at 530 m, the former producing a source/transducer elevation angle comparable to that of the July'83 sea trial. Water depth at the site was 37 m and the barge, by the very nature of its function, was acoustically 'quiet'. Groups of visual and acoustic relative bearings were recorded at each of six different directions. This was accomplished by rotating the Trackpoint transducer by 60° between each set of measurements. Over the 36 m path length, the difference between 265 acoustic and visual relative bearings exhibited a standard deviation of 1.23° compared to the 20.6° determined at sea during trial #4. Clearly the Trackpoint receiver determines the correct bearing under 'ideal' acoustic conditions even when the source/transducer angle is only 8°. The source/receiver range was then increased to 530 m, all other conditions remaining unchanged. The standard deviation of 326 pairs of comparative readings increased to 46.84°.

It was observed, during this as in many previous experiments, the display would indicate a nearly constant bearing and cursor length

(relative range) for a few fixes then suddenly behave erratically for a few fixes. Figure 4 is an illustration of this behaviour around the 250 second point for a case where the source/receiver range was 530 m and the visual relative bearing was 000. This erratic behaviour did not occur at the 36 m range but did occur often at sea during previous trials. The problem was most evident at the Acoustic Barge during the period when a small vessel came alongside, tied up, and left its propellers rotating. Few successful measurements of bearing were possible during this period. There appeared to be positive evidence that such acoustic noise dramatically affected the Trackpoint receiver performance.

The pairs of relative bearings discussed above were then re-examined. All acoustic bearings which differed from the visual bearing by more than ±15° were eliminated. This reduced the number of data pairs to 237 and the standard deviation to 6.07°. The broken lines in Figure 4 illustrate the effect of this ±15° window on the acoustic bearing data.

A somewhat subjective observation was that the operator could identify "good" versus "bad" fixes by watching the display for a few minutes. In general, a "good" fix was one where the relative bearing and cursor length remained steady over a number of consecutive fixes. A "bad" fix was one in which the cursor on the display swung about erratically and varied in length from fix to fix. To explore this concept, the Trackpoint transducer was rotated to various bearings relative to the source at 530 m range. The Trackpoint operator would watch the display for a few fixes and make a subjective judgement as to the correct relative bearing. For a set of 9 such measurements the mean bearing error was 2.0° and the standard deviation 6.6°. This result is equivalent to the result illustrated by the "windowing" process in Figure 4.

iii. Trackpoint Receiver at the BIO Jetty

Having established how the receiver behaved under very favourable acoustic conditions, it was moved to a small barge moored alongside the BIO finger jetty. The objective of this experiment was to established what effect a substantial acoustic reflector (the jetty wall or a ship's hull) would have on the receiver performance. The acoustic source was secured 5 m below a surface buoy at a range of 192 m yielding a source transducer elevation angle of 1.5°. The only ship present was the Louisburg which had its main engines and most other machinery shut down. The geometry is illustrated in Figure 5.

At five different distances from the jetty wall varying from 1.2 m to 8.5 m, sets of 80 to 130 acoustic bearing measurements were made. Figure 6 is an example of one such data set which clearly demonstrates that temporal behaviour of the receiver was similar to that at the DREA Acoustic Barge (Figure 4).

The experiment was repeated with the small barge moored outboard of CSS Hudson. This ship was moored alongside the jetty at the position shown in Figure 7. Its main engines were shut down but various auxiliary pumps, ventilation equipment and other machinery were operating. Figure 8 shows the time history of relative bearing at a distance of 8.1 m from the hull. In contrast to Figures 4 and 6, there are a substantial number of periods when the bearing error exceeded ±15°. If a comparison is made between the percentage of the total number of fixes falling within this limit for the case of the ship absent at different distances from the jetty, one finds that there is no significant change. On the other hand, there is a strong direct positive relationship between percent acceptable bearings and increasing distance in the case of the ship present as

illustrated in Figure 9. Similarly, the standard deviation of relative bearing for the cases of ship absent and present for different distances from the ship or jetty also shows these relationships as shown in Figure 10. This clearly demonstrates that the quality of the bearing measurement is unaffected by proximity to a good reflector (the jetty) but is strongly affected by a nearby noise source (the ship).

VI. SUMMARY AND CONCLUSIONS

i. Summary

The Atlantic Oceanographic Laboratory has a requirement for an acoustic receiver capable of determining the bearing of an acoustic source in deep water relative to a ship to an accuracy of ±5° to aid in mooring relocation and recovery operations. In addition, there are other sea going operations at the Institute that would benefit from this resource especially if the accuracy were better. It is essential that the equipment should be simple and unambiguous in operation, cost in order of $60000 maximum and employ a single transducer. The only unit on the market at the time of these trials that had this specification was the O.R.E. model 450 TRACKPOINT Acoustic Range/Bearing Receiver. As previous experience has shown that ambient noise effects would be the most likely reason why an ultra-short baseline receiver such as this might not meet the requirement, a sea trial was specified before purchase.

As it turned out, a total of four sea trials were conducted. On the first, a broken transducer cable prevented success, on the second bad weather and on the third a partially flooded pre-amplifier housing.

During the fourth and final sea trial, it was determined that the receiver measured bearings which correlated with visual ones but

accuracy was poor. The standard deviation in this difference was 20.6° even for selected data sets and variability appeared to be mainly caused by acoustic rather than visual bearing measurement errors. Possible sources for this error included an equipment malfunction; the effect of reflections from the ship's hull; the effect of ambient noise in the vicinity of the ship; or, violation of the specified minimum source/transducer elevation angle.

A set of experiments were designed to address this problem. The receiver was first tested under ideal acoustic conditions at the DREA Acoustic Barge in Bedford Basin. It was found that, with a source level of +195 db re 1 μ Pa @ 1 m located 36 m from the receiver transducer, the standard deviation in bearing error was 1.2°. Increasing the range to 530 m, increased the standard deviation to 6.1° and the receiver periodically failed to detect replys. When this event occurred, it would persist for several consecutive fixes while the receiver continued to display grossly incorrect but apparently valid bearings. After observing the display for sometime, it became possible to subjectively differentiate between "good" and "bad" fixes by observing the time history of the cursor movement. A rapid change in direction and length of the cursor indicated a change over from "good" to "bad" fixes or vica versa. "Bad" fixes tended to be associated with a foreshortened cursor and more variation in direction than was apparent during "good" fixes. Applying this subjective signal detection method to the problem of determining the unknown bearing of an acoustic source led to repeated determination of the direction with an accuracy of 6.6°. This seemed to indicate that, even at source/transducer angles as shallow as 0.5°, the receiver would behave properly.

The receiver transducer was then placed at varying distances

from a concrete jetty. There appeared to be little if any correlation between either the percentage of "good" vs. total fixes or the standard deviation in the bearing error as a function of distance from the jetty. This observation confirmed that the bearing measurement problems noted at sea were not likely a consequence of reflections from the ship's hull.

The receiver transducer was then placed at varying distances from the ship's hull. There was a nearly perfect correlation between both percent "good" vs total fixes and standard deviation of bearing error and the corresponding distance from the ship's hull. Furthermore, it was noted that it was nearly impossible (4.6% "good" fixes) to get valid readings when the transducer was 0.3 m from the hull even with the main engines stopped. It was also observed that the standard deviation in bearing error with the ship present was double that measured in its absence. Clearly the presence of the ship dramatically influences the performance of the TRACKPOINT receiver.

ii. Conclusions

Electronically the receiver exhibits a straight forward analogue approach to the ultra-short baseline signal detection problem and there appear to be sensible choices made about filtering and averaging. The automatic gain controls (AGC) within the receiver are rather mystifying but this is probably a measure of the author's intellectual limitations rather than the designer's. It did appear as though it might be useful to bring the three amplifier signal detection LED's out to the front panel to assist the operator in assessing "good" vs "bad" fixes. Perhaps a straight forward retro-fit would be to use optical fibres rather than rewire the receiver electrically.

Mechanically the shipboard units are well constructed. Based on the sea trial experiences, the transducer array did have some reliability problems. However, the construction method employed is unsophisticated so, providing the fault could be identified, repairs would usually be possible at sea.

Operationally, the receiver operates correctly in the presence of high signal-to-noise ratios even at very shallow source transducer elevation angles. However, as soon as the signal-to-noise ratio decreases to levels still far in excess of that normally encountered as sea, the receiver begins to display sequences of incorrect fixes and bearing accuracy is degraded. Even with the strong signal from a +195 db re 1 μ Pa @ 1 m acoustic source, contact was lost at ranges in excess of 900 m. At lesser ranges, the standard deviation of the error in the acoustic bearingswas about 21°. This problem is caused by ship generated noise rather than interference by reflections from the ship's hull.

Overall, it is the opinion of the author that the TRACKPOINT receiver performance below 12 kHz is not adequate to meet the needs of the Bedford Institute of Oceanography because of its inability to function properly in the presence of normal ship generated noise.

Acknowledgements

The author is grateful for the generosity of the Canadian Armed Forces Fleet Diving Unit (Atlantic) and in particular Lt. Cmdr. B. Martin and P.O. W. Catchpaw for their repeated generosity in loaning their Trackpoint receiver for the 1983 trials. At ORE, A. Griswold and R. Penton provided much valuable insight into the theory and operation of the system. Freedom to use the DREA Acoustic Barge in Bedford Basin was also

appreciated. And, as always, thanks to the ship's company on CSS Hudson and the Institute staff ashore who make it all happen.

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Figure Captions

Figure 1a — Configuration of the three hydrophones relative to an incoming plane acoustic wavefront which varies sinusiodally with time, and

Figure 1b — the corresponding instantaneous pressure signals at the three hydrophones as a function of time.

Figure 2 — Trackpoint acoustic and pelorous visual relative bearings vs. time aboard CSS Hudson at sea.

Figure 3 — Acoustic vs. visual relative bearing correpsonding to the time series of Figure 2.

Figure 4 — Variation of acoustic relative bearing with time at a range of 530 m at the DREA Acoustic Barge.

Figure 5 — Geometry of the receiver tests alongside the BIO finger jetty with no ship present.

Figure 6 — Variation in acoustic bearing with time with the receiver transducer 8.5 m from the BIO finger jetty and no ship nearby.

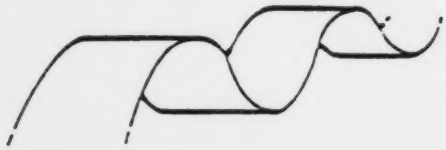
Figure 7 — Geometry of receiver tests alongside the BIO finger jetty with CSS Hudson present.

Figure 8 Variation in acoustic bearing with time with the receiver transducer 8.1 m from the hull of CSS Hudson alongside the BIO finger jetty.

Figure 9 Percent of acceptable replies within ±15° for limits for presence and absence of CSS Hudson as a function of distances from the ship or jetty.

Figure 10 Standard deviation of relative bearings as a function of distance from the ship or jetty with and without the presence of the ship.

(a)



APPROACHING
ACOUSTIC PRESSURE
WAVE

Figure 1a Configuration of the three hydrophones relative to an incoming plane acoustic wavefront which varies sinusiodally with time, and

(b)

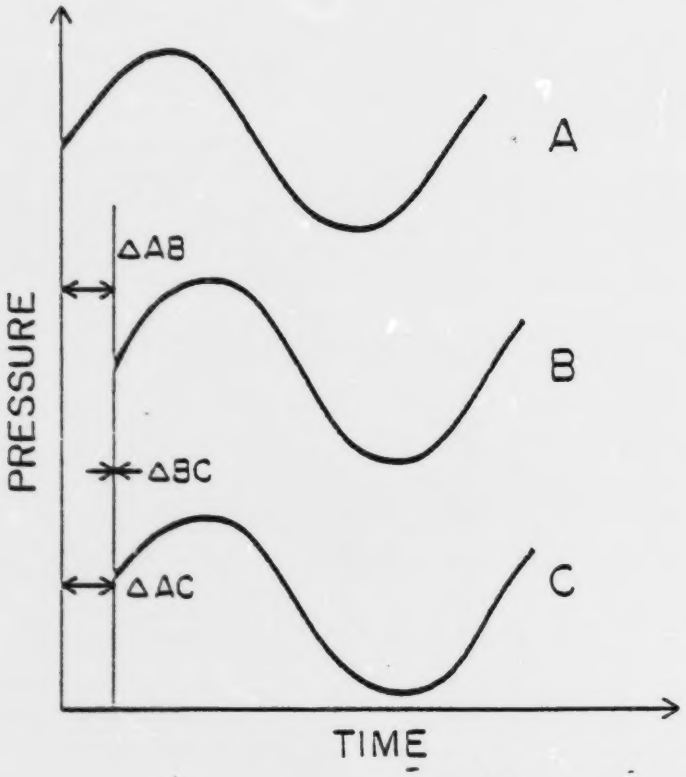


Figure 1b the corresponding instantaneous pressure signals at the three hydrophones as a function of time.

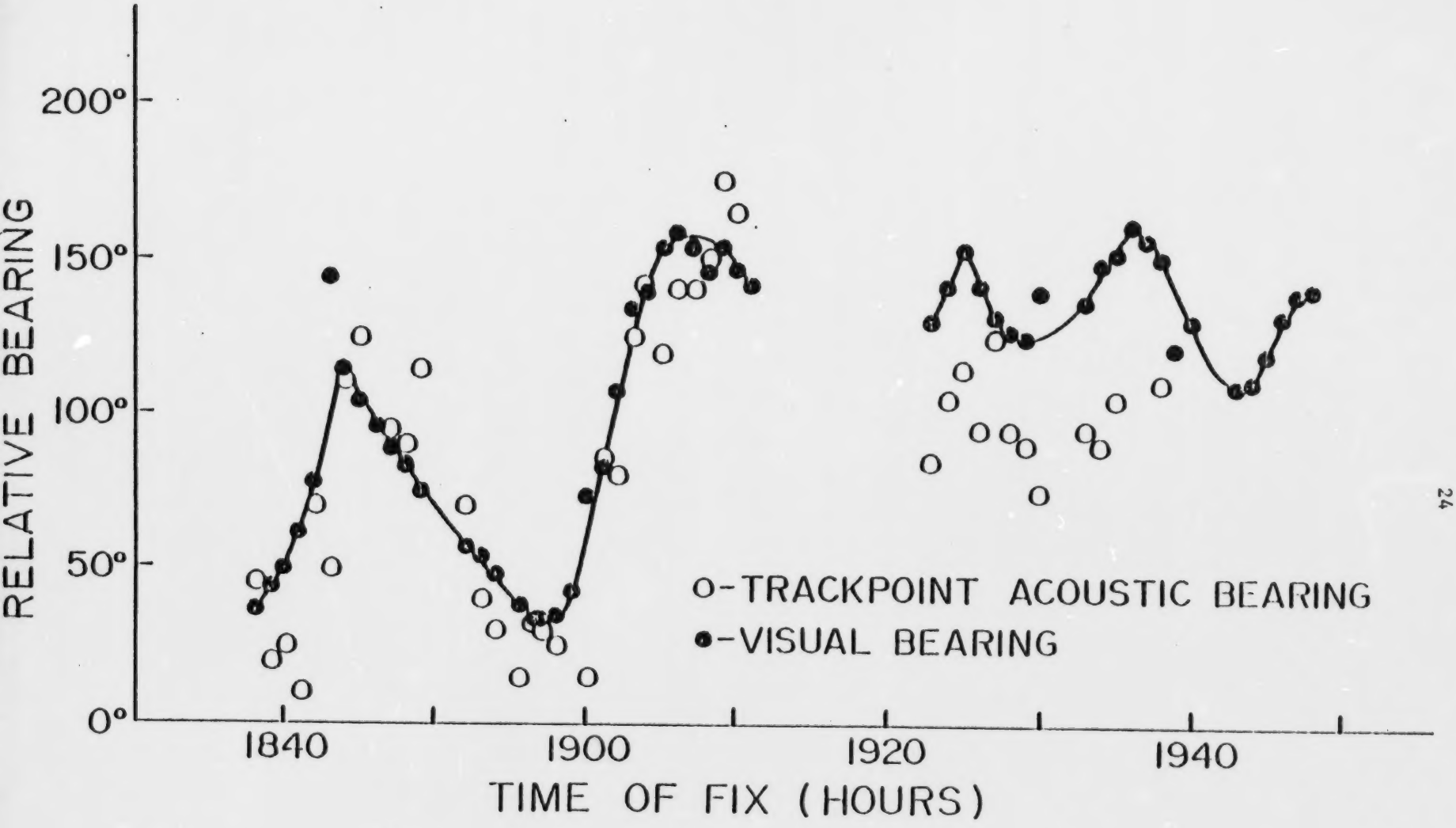


Figure 2 Trackpoint acoustic and pelorous visual relative bearings vs. time aboard CSS Hudson at sea.

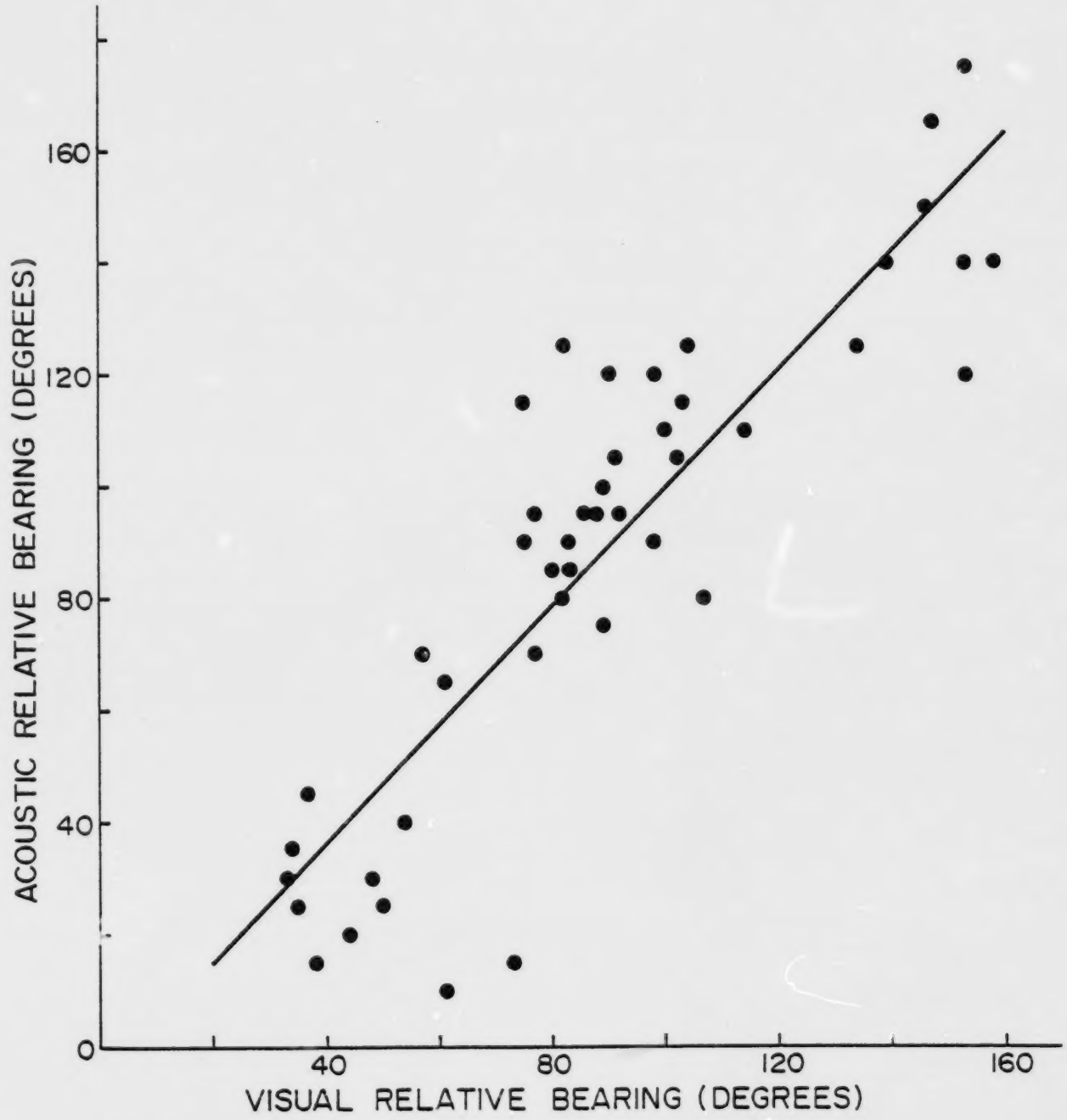


Figure 3 Acoustic vs. visual relative bearing correpsonding to the time series of Figure 2.

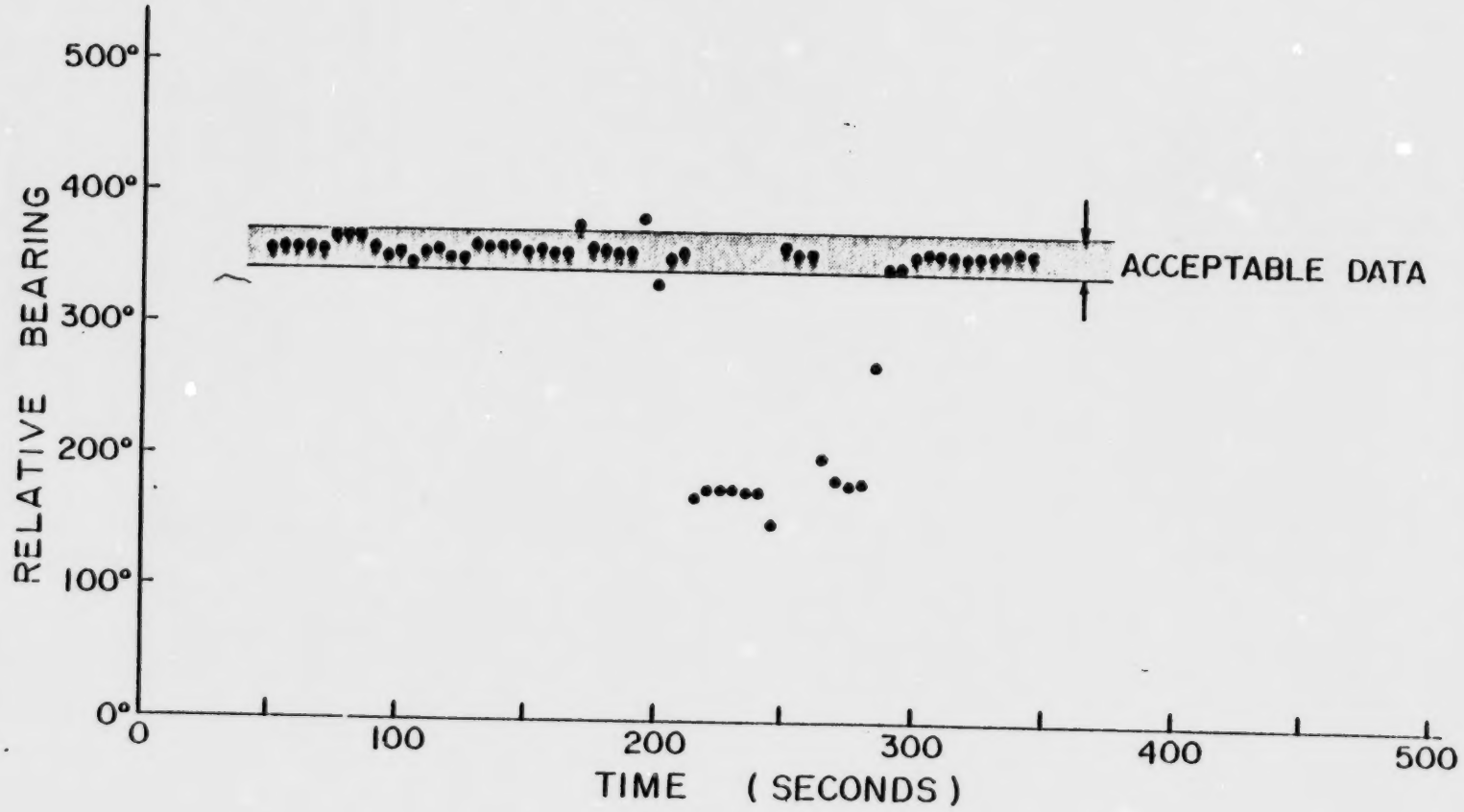


Figure 4 Variation of acoustic relative bearing with time at a range of 530 m at the DREA Acoustic Barge.

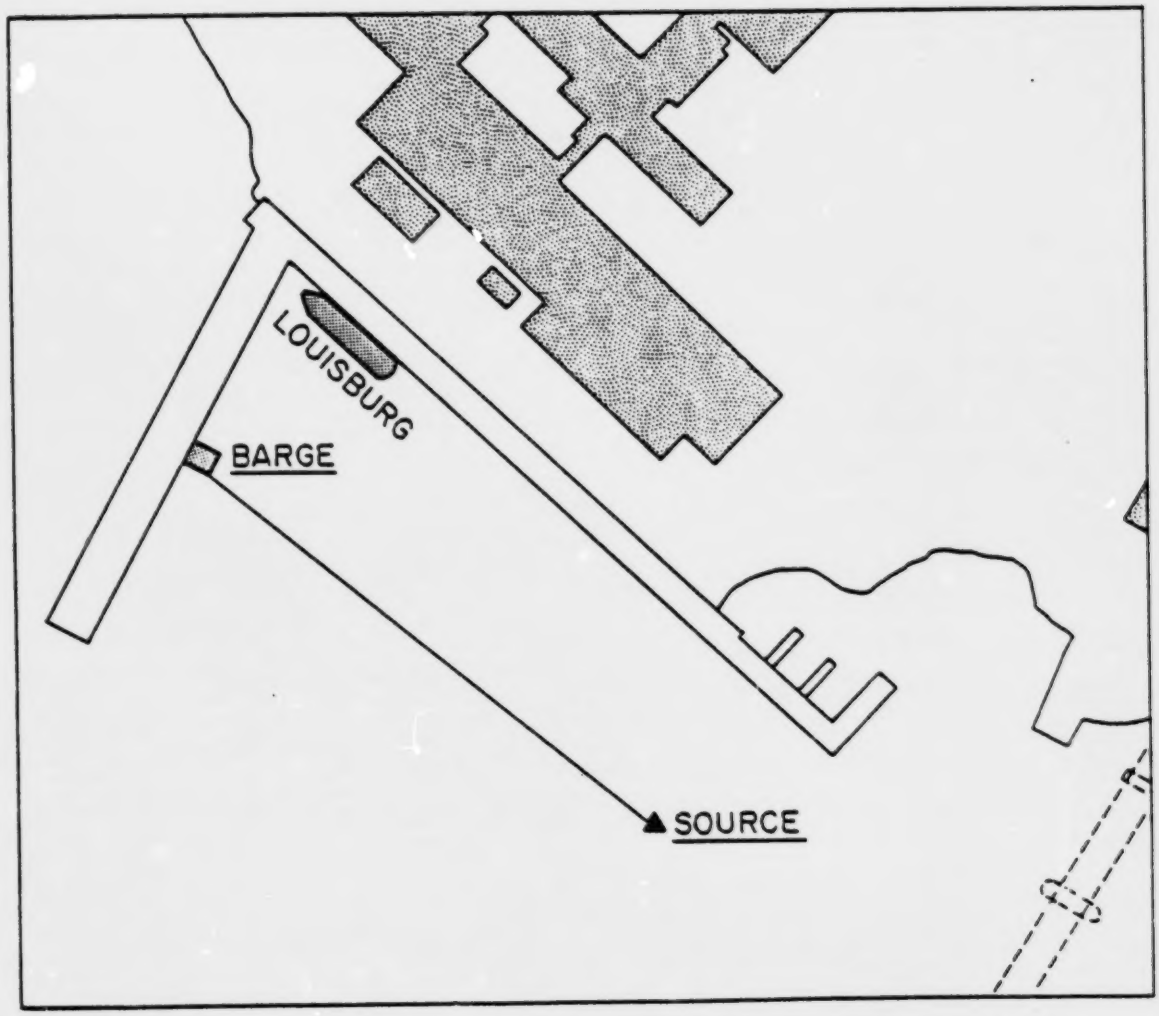


Figure 5 Geometry of the receiver tests alongside the BIO finger jetty with no ship present.

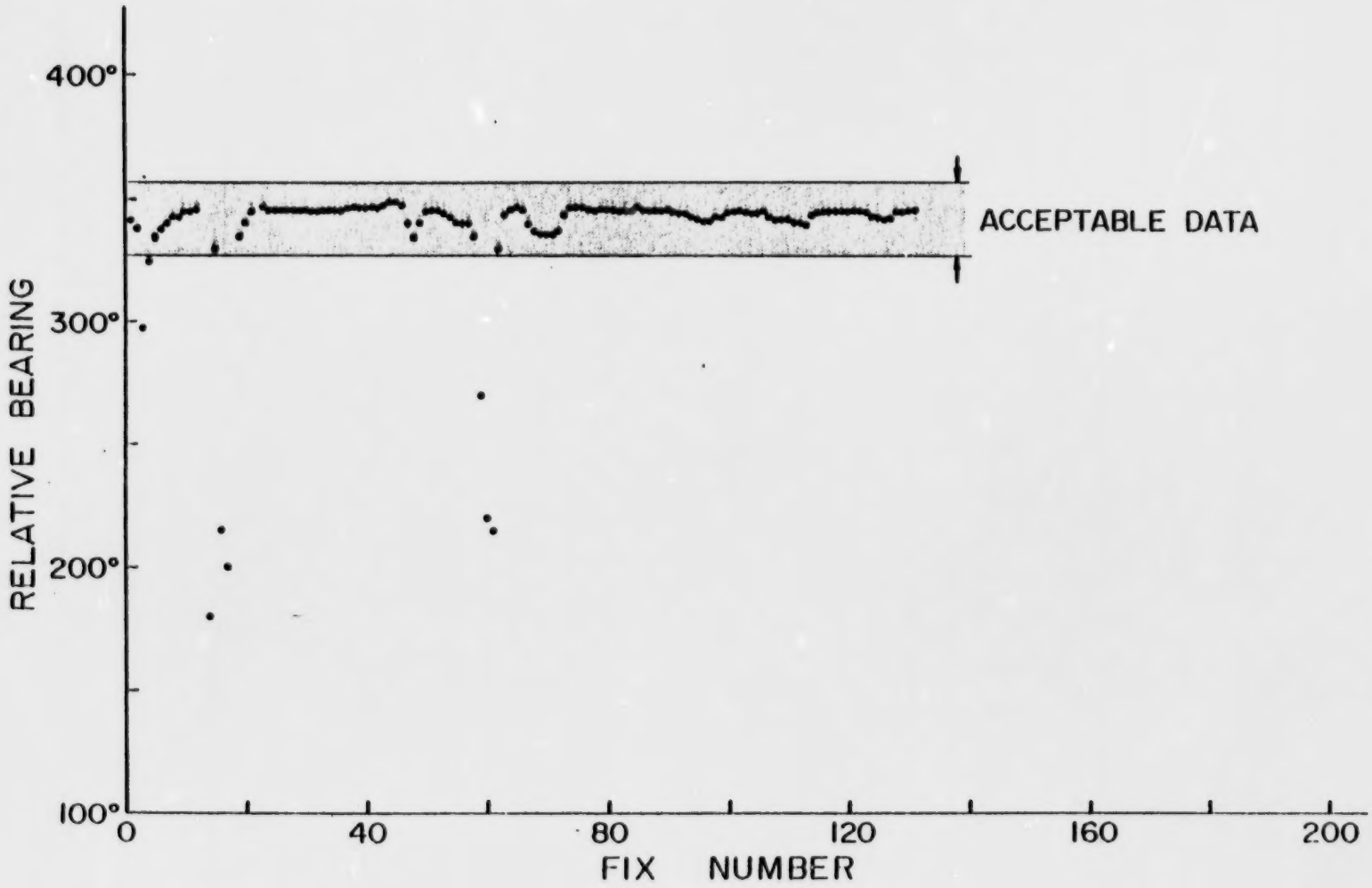


Figure 6 Variation in acoustic bearing with time with the receiver transducer 8.5 m from the BIO finger jetty and no ship nearby.

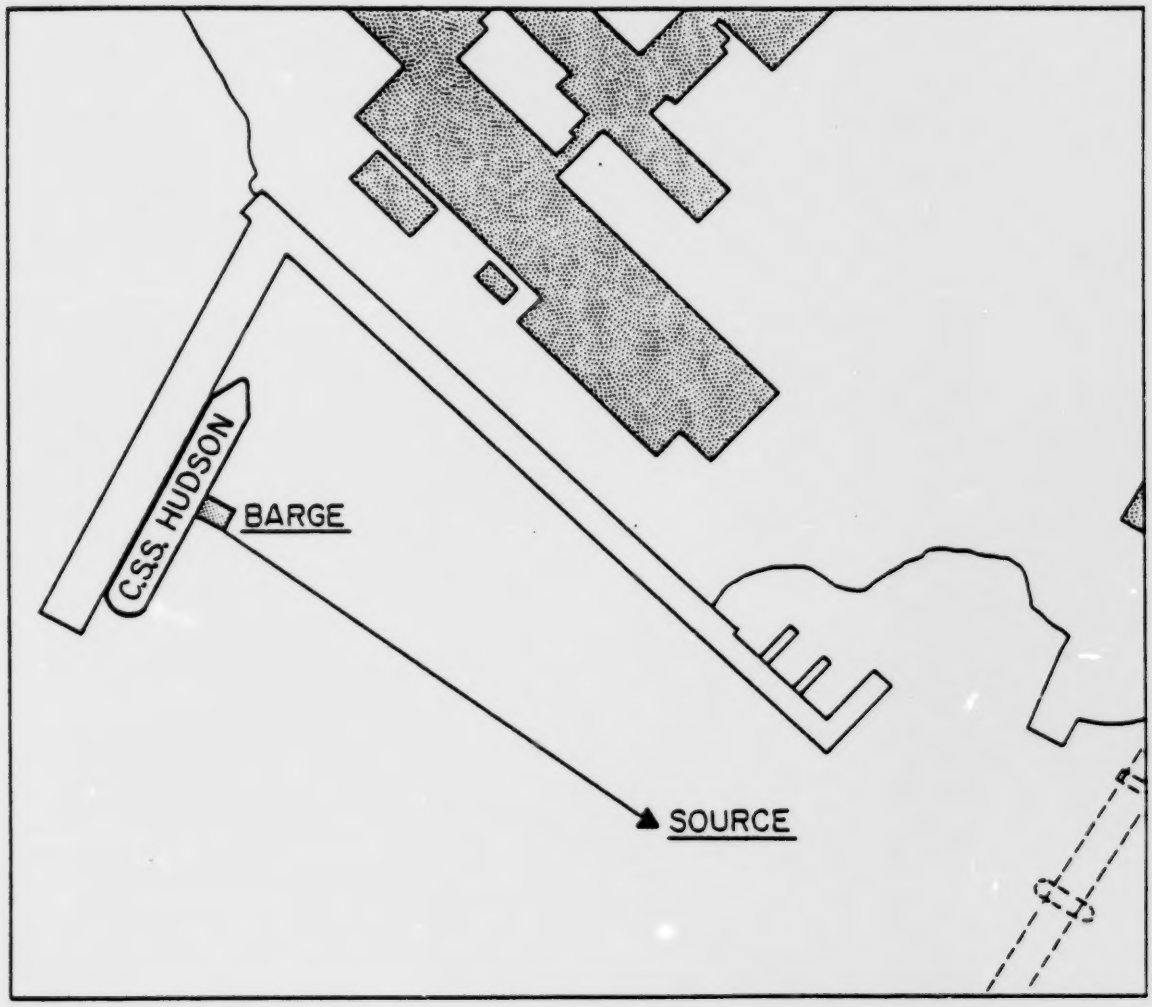


Figure 7 Geometry of receiver tests alongside the BIO finger jetty with CSS Hudson present.

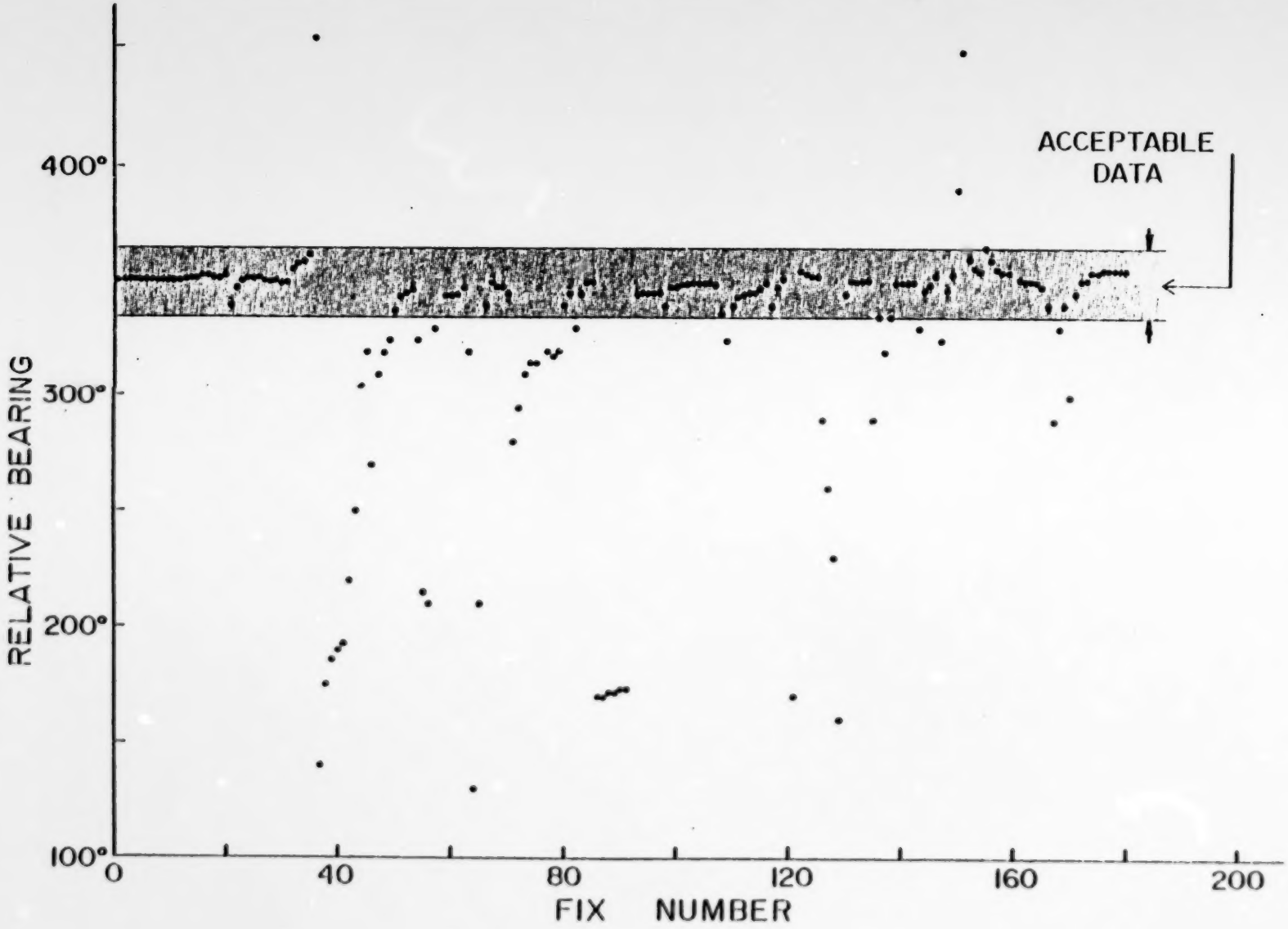


Figure 8 Variation in acoustic bearing with time with the receiver transducer 8.1 m from the hull of CSS Hudson alongside the BIO finger jetty.

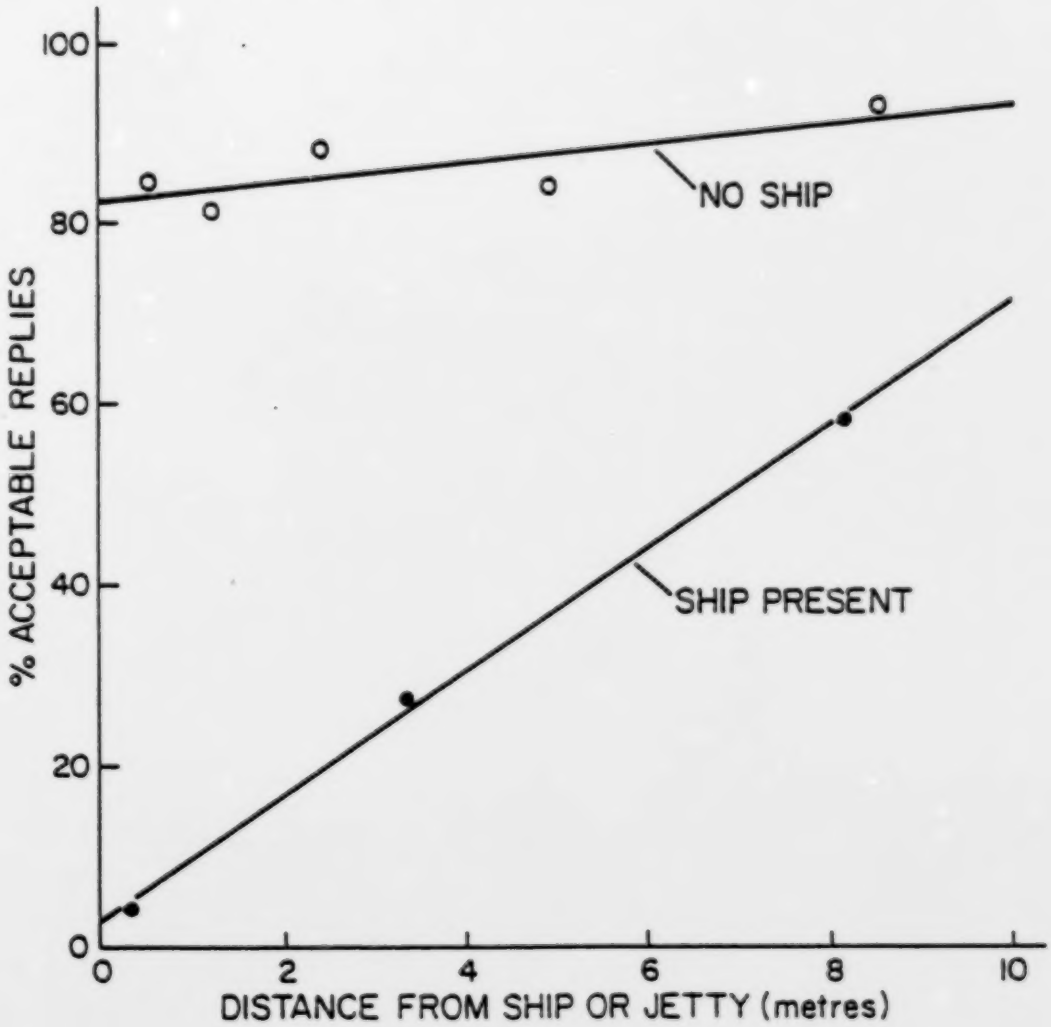


Figure 9 Percent of acceptable replies within ±15° for limits for presence and absence of CSS Hudson as a function of distances from the ship or jetty.

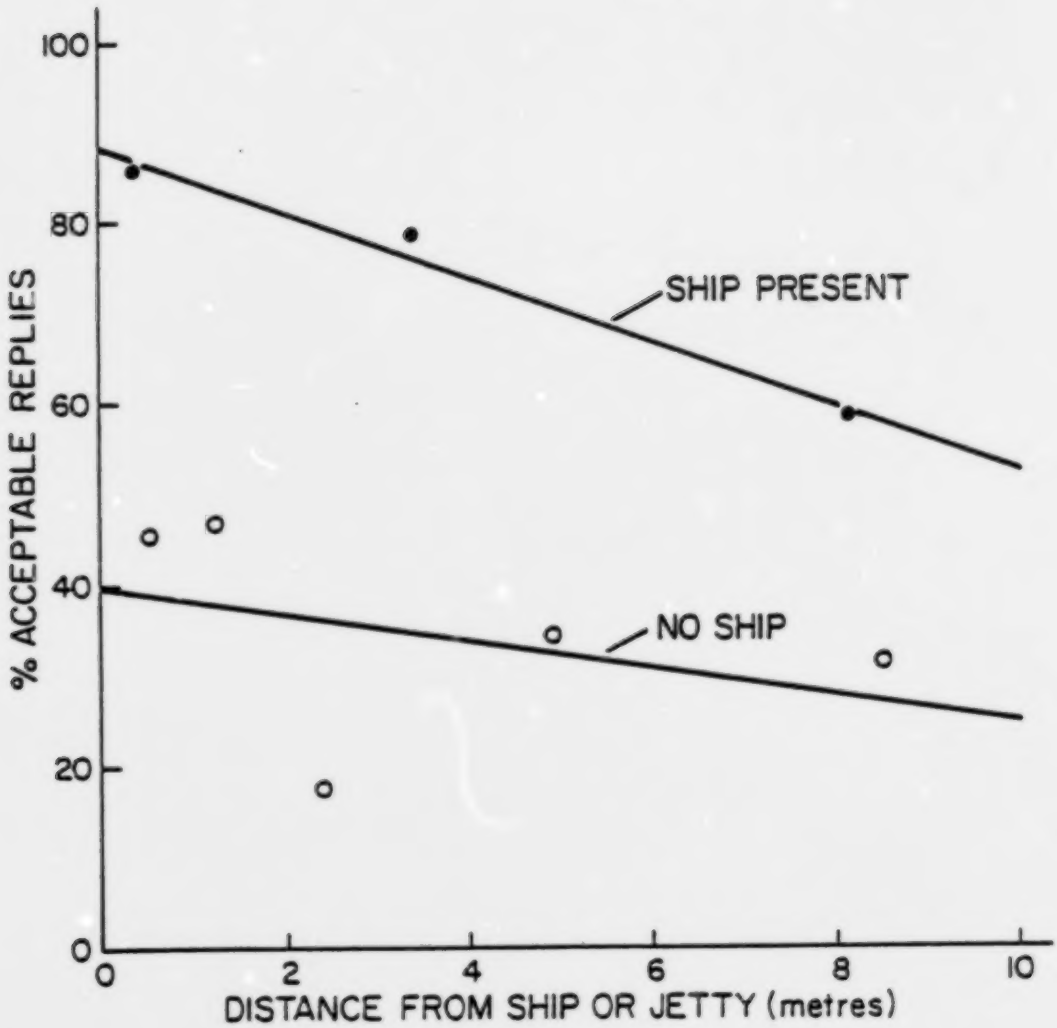


Figure 10 Standard deviation of relative bearings as a function of distance from the ship or jetty with and without the presence of the ship.

APPENDIX

TRACKPOINT

ORE Model 450B Acoustic

Range/Bearing Unit Specification

Note: This specification is reprinted from revision 1 of the manual dated August 1980.

1.3 Specifications

1.3.1 Range/Bearing Indicator Model 450

Performance:

- Bearing Accuracy:	±.5°. When angle of signal source is greater than 10° from vertical. (Accuracy is a function of the operating cone angle and hydrophone used).
- Range Accuracy:	±0.5% of reading ±1 meter
- Target Range:	Up to 5 miles detection range depending on signal source strength, ambient noise and water-column geometry.

Receiver:

- Bandwidth:	10 kHz - 30 kHz
- Frequency:	Three preset operating frequencies with 2 kHz minimum separation (field alterable).
- Gain Control:	20, 40, or 60 db step attenuation of input signal or 80 db automatic gain control on ambient noise and signal levels.

Interrogator:

- Frequency:	7.5 kHz standard (may be varied to individual customer requirements).
- Source Level:	+98 db re 1 µbar at 1 yd
- Ranging Interval:	Off, 3, 5, or 10 sec.

Slant Range Display:

- Type:	5-digit gas discharge
- Character Height:	0.55 inches
- Viewing Distance:	40 feet
- Scale:	Feet or meters. Factory preset to customer requirements (can be field changed).
- Resolution:	±1 digit (±1 ft or ±1 meter)

Bearing Display:

- Type:	4 inch diameter CRT
- Bearing Scale:	0 to 360° in 10° increments, markings and extended lines at 30° intervals.
- Horizontal Offset Scale:	Radial circles at 20, 40, 60, 80 and 100% source depth.

Power Requirements:

- Voltage:	110V (220V optional)
- Frequency:	50/60 Hz
- Power:	50 watts max

Mechanical:

- Construction:	Standard 19 inch panel electronics mounted in an aluminum weatherproof enclosure
- Case:	10" H x 21" W x 24" L overall (25.4 x 53.3 x 61.0 cm)
- Weight:	68 lb (31 kg)
- Mounting:	Desk top or rack panel
- Sealing:	Splashproof with case cover intact.

Operating Environment:

- Temperature:	+32°F to +122°F Shade conditions (0°C to +50°C)
- Humidity:	100%, non-submersible

1.3.2 Receiving Hydrophone Model 441

- Type:	3-element ceramic phase array
- Operating Band:	Model 441A 10 kHz - 16 kHz Model 441B 15 kHz - 22 kHz Model 441C 20 kHz - 30 kHz

NOTE

Higher frequency band model may be used with lower frequency source with some degradation in performance. (See sections 3.10 and 3.11).
Refer to Section 7.3 for various hydrophone configurations and operating limits.

- Size: 4.5"D x 10.1"L (11.4 x 25.7 cm) overall
- Weight: 7.1 lb (3.2 kg) in air maximum
- Cable Length: 200 feet maximum

1.3.3 Hydrophone Gimbal Assembly (optional)

- Type: 2 axis gimbal movement
- Compensation Range: ±20°
- Housing: plastic sphere
- Mounting: fixed over-the-side staff
- Size: see figure 4-4
- Weight: 20 lb (9.1 kg) in air

1.3.4 Hydrophone Fixed-Mount Assembly

- Mounting: fixed over-the-side staff
- Size: see figure 4-3
- Weight: 14.5 lb (6.6 kg) in air

1.3.5 Interrogating Transducer Model 601C

- Type: single element ceramic cylinder
- Frequency: 7.5 kHz standard
- Mounting: over-the-side cable suspension
- Size: see figure 4-2
- Weight: 7.3 lb (3.3 kg) in air

1.3.6 Vertical Reference Unit (optional)

- Axis: 2
- Motion Sensor: precision pendulum potentiometer
- Compensation Range: ±20° pitch and roll
- Size: see figure 4-5
- Weight: 29 lb (13.2 kg)

1.3.7 Signal Source Requirements

- Type:

	REQUIREMENT		
	Bearing	Horizontal Offset	Slant Range
Transponder	X	X	X
Responder	X	X	X
Pinger	X	X	
Beacon	X	X	

- Pulse Length: $\frac{100}{\text{operating frequency}}$ seconds minimum

- Repetition Rate: no limit